CEMENT AND LIME MANUFACTURE

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Special Cements.

By C. R. PLATZMANN

THE first materials to compete with normal Portland cement were iron Portland cement and blastfurnace Portland cement, which were developed in Germany where the annual production now exceeds 500,000 tons. To-day there are many cements of different types and it is probable that their number will be added to. These special cements have been developed to meet new problems, but it seems that the number of special cements already exceeds all reasonable limits and has made the possibility of an international standard specification more difficult.

The different cements are briefly described in the following, and an attempt is made by a method similar to that used by Dr. H. Kühl some years ago to classify the different cements now available according to their application in practice.

Ordinary Portland cement, of course, is used for the bulk of the concrete placed throughout the world, and is satisfactory even in cases where it may be claimed that a special cement would be more suitable. Many special cements are merely modified Portland cements. The oldest special cement, the so-called ore Portland cement, only differs from true Portland cement by an increased resistance to the attack of sulphate solutions, and this quality can be obtained by lowering the alumina content and increasing the content of ferric oxide, whereby the danger of the formation of calcium sulphur aluminate is reduced.

High-Early-Strength Cements.—High-early-strength Portland cements are also true Portland cements, differing from normal Portland cement by an increased lime content up to the limit of the lime saturation factor, by increased fineness of grinding, and by burning the clinker at a somewhat higher temperature.

After the high-early-strength cements come the higher-early-strength cements, which, when mixed with sand in the proportions of 1 : 3, attain compression

strengths up to 10,400 lb. per square inch. Occasionally small additions of strength-increasing compounds such as calcium chloride have been used for the manufacture of this type of cement. It is interesting to note that efforts to obtain equally high increased tensile strengths have failed.

Relation between Compression and Tensile Strengths.—In the early days of Portland cement the relation of compression strength to tensile strength was about 10 : 1. It is now, for normal Portland cement, about 13 : 1. The relation is still less favourable for high-early-strength cements. An increase of compression strength seemed necessary to meet the requirements of modern design, but it should be limited if an appreciable increase of tensile strength is not attained. The special advantage of the so-called steel-concrete (cement with metallic aggregate which is highly resistant to abrasion) consists in the fact that by using graded cast iron as aggregate the tensile strength is improved up to 1,030 lb. per square inch at 28 days, with consequently greater resistance to abrasion and impact. Such properties are often far more desirable than very high compression strength which cannot always be taken advantage of in practice. A prominent German architect recently told the author that a mortar with compression strength up to 10,400 lb. per square inch would not interest him, because he would not be able to make profitable use of more than a quarter of that strength. Such considerations are apparently the cause of the present tendency to introduce into the standard specifications the testing of the flexural strength by using a plastic mortar with grain-size aggregate, thus attaining a close relation to the conditions in practice. Finally, it must be remarked that generally the high-early-strength cements tend to shrink more than ordinary Portland cement, and for this reason engineers often prefer to use normal Portland cement when time permits.

White Cement.—White cements, with the exception of a French brand, are also true and standard Portland cements differing from grey cement solely in the use of raw materials which are as free as possible from iron oxide contaminations, and the strengths of white Portland cements are naturally the same as grey cements. The cost of manufacturing this type is relatively high.

Coloured Cements.—Coloured cements are manufactured by adding mineral pigments to white cement, and are mainly used for rendering and road surfaces. The problem of colouring cements satisfactorily has been solved by grinding the cement clinker and pigment together, thus ensuring equal distribution of the colour. These coloured cements are not true Portland cements, being rather mixed cements. Since, however, the strength of modern cements is far above the requirements of the standard specification, any small reduction of strength is immaterial ; the proportion of pigment is usually from 6 per cent. to 10 per cent. by weight.

Pozzolana Cement.—All pozzolanic cements are also mixed cements. According to the different pozzolanas occurring in the world, different types of pozzolanic cements have been developed. The pozzolanas comprise not only

naturally occurring materials such as those in Germany and Italy, but also manufactured materials such as burnt shale or burnt "gaize," the latter being a porous siliceous rock from the Ardennes mountains and the Meuse valley in France. The most familiar natural pozzolanas are (1) Santorin earth from the Greek island Santorin, (2) Italian pozzolanas from the neighbourhood of Naples, (3) German trass from the Rhineland.

Two types of trass cement are manufactured in Germany, one containing 70 per cent. of cement and 30 per cent. of trass, the other containing equal parts by weight of cement and trass. It is claimed for trass cements that the mortar or concrete will have a higher elasticity, that it will be more impermeable (especially if the aggregate is lacking in fines) and that it possesses an increased resistance to chemical corrosion. The reason for this increased resistance to chemical attack is unknown. For a long time it was supposed that the silica soluble in hydrochloric acid and present in pozzolana combined with the calcium hydroxide and separated from the cement in amounts from 7 per cent. to 17 per cent. during the setting and hardening by forming additional hydrosilicates of calcium, but as these are not resistant to acids the explanation must be elsewhere. According to recently published experiments carried out by Steopoe it is believed that the hydrosilicates of calcium formed are hydrolysed by forming acid-resisting silica gel in the surface voids of the mortar or concrete.

Low-Heat Cements.—Pozzolana and trass cements are interesting in the construction of mass-concrete work, such as large dams. Especially in the United States and Sweden it was necessary to use an hydraulic binder which generated during setting and hardening less heat than that developed by normal or high-early-strength cements. A high and prolonged rise of temperature in the core of the concrete caused cracks which were highly undesirable. If the amount of cement in the hydraulic binder is appreciably reduced, as in pozzolanic or trass cements, the heat of hydration is reduced in the same ratio as the proportion of cement is lowered in the mix. The hardening is retarded when using pozzolanic cements, although the final strength is not less. For the same reason iron Portland and blastfurnace cements are occasionally preferred for the construction of mass concrete, since they develop less heat of hydration.

There is another way of producing low-heat cements, for experiments show that tricalcium aluminate is the constituent of cement which generates the largest amount of heat. By limiting the amount of this compound a cement is produced which possesses the required properties for mass concrete work. In this case, too, the rate of hardening is retarded without any reduction of the final strength of the concrete.

Water-Repellent Cement.—Water-repellent cements contain a percentage of stearate salts. They are principally used for making cellars impermeable to the accession of ground water and in rendering work.

Masonry Cements.—In the United States for many years past so-called masonry cements of very different compositions have been made with the idea of improving the workability of concrete and retaining the gauging water as

long as possible. Those who are specially interested in these types of cement are referred to Lea and Desch's book " The Chemistry of Cement and Concrete."

Iron and Blastfurnace Portland Cements.—Iron Portland and blastfurnace cements, which are mainly produced on the Continent, consist of mixtures of Portland cement clinker with granulated blastfurnace slag. High-early-strength cements of this type are also made. It was for some time doubted whether these cements were of equal value to ordinary Portland cement, but this question is solved by the inclusion of all three cements in the latest German cement specifications, the only difference being in the definition. It has often been claimed that cements containing slag have better resistance to chemical attack on account of their lower lime content. This is, however, without practical importance, since these cements are also attacked by chemical solutions such as acids or sulphates. For pre-cast concrete and renderings it seems advisable to use ordinary Portland cement, since cements containing slag may cause discoloration on account of their relatively high content of sulphides. For other work cements containing slag are as useful as ordinary Portland cement.

In Belgium a slag cement rich in sulphate is manufactured by combining blastfurnace slag with gypsum. It is claimed that this cement has a specially good resistance to the attack of sulphates and sea-water.

Quick-Setting Cement.—Finally a quick-setting cement may be mentioned, consisting of ground Portland cement clinker without any addition of gypsum ; so far as the author is aware there is in Germany only one factory producing this cement.

Aluminous Cement.—The main compound of aluminous cement is calcium aluminate. This cement is characterised by high-early-strengths and by improved resistance to the attack of sulphate solutions, but its use at high temperatures—above 35 deg. C.—leads to difficulties and loss of strength.

Classification of Cements.

The different cements available fall into the following groups :—

(1) Portland cement.—Standard Portland cement ; High-early-strength cement ; Higher-early-strength cement ; Ore cement ; White cement ; Low-heat cement.

(2) Slag-containing cements.—Iron Portland cement : High-early-strength iron Portland cement ; Blastfurnace cement ; High-early-strength blastfurnace cement.

(3) Aluminous cement.

(4) Mixed cements.—Pozzolanic cement ; Trass cement (two types) ; Gaize cement ; Moler cement (low heat of hydration).

(5) Special cements.—Quick-setting cement ; Masonry cement ; Slag cement (rich in sulphates) ; Water-repellent cement.

It is seen from this list that, starting from the original Portland cement, some twenty types of cement have been developed. It is not easy to understand

why a problem, originally simple, has been complicated in this way, and it may be pointed out that normal Portland cement still accounts for approximately 80 per cent. of the world's production. It would seem that some of the newly developed cements are superfluous. It is not certain that the so-called higher-early-strength cement is a necessity, because the one-sided over-valuation and development of compressive strength is no advantage so long as the tensile strength is not increased in the same degree. Masonry cements can also be considered to be superfluous because lime-cement mortar has for decades achieved the same purpose. With regard to quick-setting cement, it may be mentioned that quick-setting compounds have been available for many years, and these are sufficient. Slag cement rich in sulphates cannot be considered as indispensable, because ore cement, aluminous cement, and the different types of pozzolanic cements seem to fulfil the same purpose.

It is not easy to decide which type of cement should be used in special cases, and this uncertainty has occasionally been the cause of failures. It seems therefore necessary to classify the cements available according to the main applications in practice, as follows:

(1) High buildings and underground work,
(2) Mass concrete (dams, etc.),
(3) Concrete with reduced shrinkage (roads, rendering, pre-cast concrete, etc.),
(4) Chemical resistant concrete.

Group (1) comprises all standard Portland cements, iron Portland cement, blastfurnace cement, and high-early-strength cements; Group (2) will require ordinary Portland cement, pozzolanic cements, and low-heat cement. For works in Group (3) pozzolanic cements, white cement, coloured cement, and ordinary Portland cement seem to be more suitable. In the case of Group (4), ore cement, aluminous cement, and pozzolanic cements should be mainly used.

The Stockholm Conference on Cement.—The *Proceedings* of the Symposium on the Chemistry of Cements, held at Stockholm last year, are now available in book form, and can be obtained from Cementlaboratoriet, I.V.A., Stockholm 5, Sweden, price 30s., plus 2s. for postage. The papers and discussions are printed in the English language.

Measurement of Shrinkage of Concrete.

IN an article in a recent number of *Concrete and Constructional Engineering*, Mr. Russell V. Allin, M.Inst.C.E., states :

The shrinkage of concrete is affected by several conditions of workmanship and quality, and has been estimated by different authorities at ultimate values ranging from 0·0002 to 0·0006 in. per inch (in length), full shrinkage being reached in about sixty weeks. The wide variation in the estimated figure is chiefly due to the dependence of shrinkage on richness of mix, quality of cement, and method of curing, and to a smaller degree on the water-cement ratio. Moreover, these figures are based on the use of impervious aggregates, and slightly higher figures will be obtained with porous aggregates.

It is clear that in construction, where the question of shrinkage cracks is one of importance, and also in underpinning work, it is particularly desirable to have a ready means of investigating this factor on the site and therefore under the special conditions in which the concrete will be placed and cured.

The method of measurement to be described has been devised by the writer and successfully used by him to determine shrinkage values on the site. This device has the merit of simplicity, since no apparatus is required except an ordinary steel erector's feeler gauge capable of measuring to 1/1000th of an inch. A bar of concrete of the quality to be tested and about 2 in. square is made in a mould lined with greased paper whose sides can be removed without undue disturbance of the freshly placed concrete. In this are set two steel bars (*Fig.* 1)

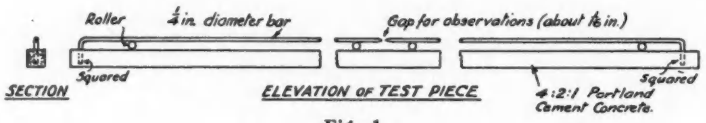


Fig. 1.

of about ¼ in. diameter, the extremities of which are placed in the concrete at a distance apart convenient for purposes of ready calculation. A distance of one hundred inches has been found to be suitable, thus making the block about 8 ft. 8 in. long. These bars should be carefully aligned and their adjacent ends should almost meet, leaving a gap at the centre of a width of not more than the full capacity of a feeler gauge (about 1/16 in.) for periodic measurements of shrinkage.

The sides of the mould should be removed immediately the concrete has set sufficiently to allow this to be done, in order that the restraint imposed by them upon the concrete during setting should be reduced to a minimum. A puddle stank can easily be made around the specimen for curing purposes.

It is important that the ends of the bars at the gap should be tapered and filed so that their end surfaces are parallel and vertical and therefore allow of

no variation in the manner of applying the feeler gauge when taking observations. They should also be kept greased. It is also important that the ends of the bars which are buried in the concrete should be squared or roughened to prevent turning (*Fig.* 1).

Results of Test.

In *Fig.* 2 are shown the results of tests on two specimens, viz., (1) Ordinary

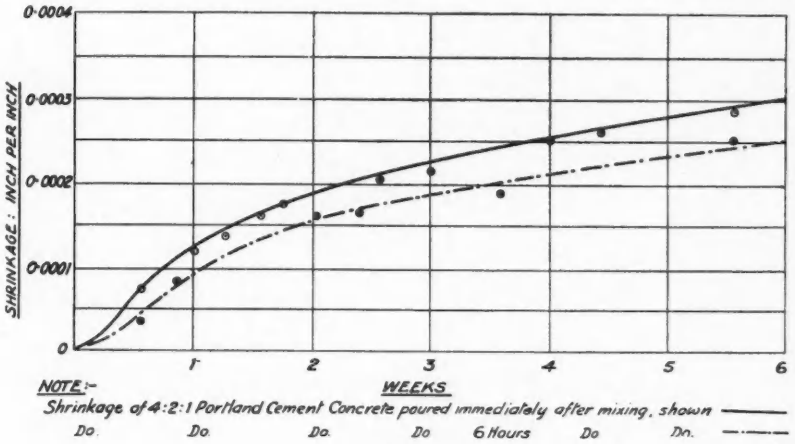


Fig. 2.

Portland cement concrete, 4 : 2 : 1 mix, ¾-in. aggregate, 5-in. slump, placed in the mould immediately after mixing; and (2) A similar concrete, but placed in the mould six hours after mixing when the slump had thereby been reduced to ½ in. A third specimen was centrally reinforced for its full length with a ½-in. diameter bar.

It will be noted that the period of the shrinkage observations has not been carried beyond six weeks, as this was sufficient for the purpose for which they were required. When plotted to a smaller scale it will be seen that the general shape of the curves, which are in the nature of asymptotes, would indicate an ultimate shrinkage of about 0.0004 in. per inch in the case of the concrete placed immediately after mixing; but in that of the "preset" concrete it was perceptibly less, due, probably, to the loss of water by draining and evaporation which had occurred during the period it had been allowed to set before it was placed in the mould. The specimen reinforced with the ½-in. bar showed that the bodily shrinkage had been practically controlled thereby, as subsequent examination under a strong magnifying glass failed to reveal any hair cracks.

These graphs illustrate the degree of accuracy obtainable by this method of observation, which enables useful tests to be carried out on the works at negligible cost and with results comparable in their utility with those obtained in the laboratory.

Composition of Portland Cement and Heat of Solution of Clinker.

THE influence of the composition of cement on the heat of solution of commercial Portland cement clinker is discussed in Research Paper No. 1135 published by the American National Bureau of Standards by Messrs. Herbert Insley, Einar P. Flint, Edwin S. Newman, and J. Arthur Swenson.

The report is summarised as follows in the Cement Mill Section of our United States contemporary *Concrete*.

The report brings out the point that differences between quantitative microscopic analysis and compound composition calculated from chemical analysis have systematic relationships with the chemical composition of the clinker. The heats of solution calculated from compound composition by microscopic and by chemical analysis show fair correspondence with the observed heats of solution. Assumptions on which both methods of calculation are based are shown to be somewhat faulty.

Accuracy of Assumptions.

It has long been recognised that many of the properties of concrete are dependent in part on the relative proportions of the compounds which are present. Determinations of the contributions of individual compounds to the properties of cements and concretes have been based on the assumptions of previous investigators that the cement clinker is completely crystalline and that no more than six phases—$3CaO.SiO_2$, $2CaO.SiO_2$, $3CaO.Al_2O_3$, $4CaO.Al_2O_3.Fe_2O_3$, free CaO, and free MgO (periclase)—are present.

The accuracy of such methods depended in large part on the validity of these two assumptions. The recent development of a method for the microscopic examination of polished and etched specimens of Portland cement clinker using reflected light permits ready distinction of the constituents and precise determination of the boundaries of individual crystals. The combination of this method with one for measuring the relative amounts of the different constituents makes possible a quantitative and qualitative comparison of the phases actually present in the clinker with those calculated from the chemical analyses.

The report makes such comparisons for a series of commercial cement-clinker samples and compares the heats of solution obtained by calculation from both microscopic measurement and chemical analysis with the experimentally determined heats of solution.

Materials.

Twenty-six different samples of clinker were available for this study from five different sources. These included ten samples of " modified low-heat " (type B) clinkers representative of nine brands of cement used in dam construction by the Tennessee Valley Authority (designated by index letter T), three samples of clinker representative of " modified low-heat " cements used in the construction of the Tygart River Dam, West Virginia (designated by index letter W), and two samples of clinker representative of " low-heat " cements used in the construction of Boulder Dam (index letter B). A fourth source was a group of 50 samples of clinker obtained through the co-operation of the senior drainage engineer of the U.S. Department of Agriculture (index letter M). Ten samples showing wide variations in composition were chosen from this group after a study of the analyses of the corresponding cements. A single sample obtained from the manufacturer (index letter P) is listed because its Al_2O_3 and Fe_2O_3 content is low and its CaO content high.

The pure compounds used for the determination of heat of solution were obtained from several sources. Tricalcium aluminate and $4CaO.Al_2O_3.Fe_2O_3$, which were procured from Mr. William Lerch, were examined microscopically and found to be essentially homogeneous. Samples of CaO and MgO were obtained by heating the chemically pure carbonates at about 1,400 deg. C., and $\beta 2CaO.SiO_2$ was made by heating $CaCO_3$ and SiO_2 in the proper proportions together with an amount of H_3BO_3 sufficient to give 0·2 per cent. of B_2O_3 in the final product.

Discussion of Results.

Although the presence of glass is evidence that commercial clinkers are not the product of crystallisation under equilibrium conditions, the simultaneous occurrence of fine-grained crystalline light and dark interstitial material with glass in the same specimen indicates also that the clinkers have not been completely quenched. The commercial product may, therefore, be considered as an intermediate stage between a material quenched from a definite temperature and one crystallised at continuous equilibrium conditions.

In comparing calculated and observed heats of solution it is evident that, in general, the heats of solution as computed from calculated compound composition agree somewhat better with the observed than do those calculated from microscopic analysis, the average difference between observed and microscopic analysis being 8·3 cal. per g. and between observed and calculated compound composition being 5·6 cal. per g. In making the heat-of-solution calculations based upon the Bogue method of determining compound composition, it was assumed that :

(1) The compounds calculated to be present had the compositions and the heats of solution of the pure compounds unaffected by solid solution.

(2) The oxides present in minor amounts, such as alkalis, did not enter into compounds or affect the heats of solutions.

(3) Perfect equilibrium crystallisation took place during cooling without the formation of glass.

In making the calculation of heats of solution from microscopic analyses it was not only necessary to use the heats of solution of the pure compounds but also to use the heat of solution of $3CaO.Al_2O_3$ for all the crystalline dark interstitial material, whether rectangular or prismatic. A constant value of 700 cal. per g. was used for all the glass, although the composition and consequently the heat of solution of the glass vary with the composition and rate of cooling of the clinker specimen.

All the assumptions made with respect to both types of calculation are known to be inexact, but they are felt to be the closest approximations that can be made at the present state of knowledge. Considering the errors in the basic assumptions, the degree of correspondence of either of the methods of calculations with the observed heats of solution has little significance.

The glass content by the Lerch method is greater than the glass content by the microscopic method for all samples on which determinations were made. Because the Lerch method is essentially a heat-of-solution method it is open to some of the same errors (already pointed out by Lerch and Brownmiller) that affect the calculation of heat of solution from compound compositions, namely, the assumption that the compounds present are free from solid solution and the assumption that the alkalis and other minor oxides have no effect on the heat of solution. The accuracy of the method will be increased as more knowledge is obtained of the actual composition and properties of these compounds in cement clinker.

The results of the chemical and microscopic analysis and heat-of-solution measurements on the 26 samples of commercial Portland cement clinker examined indicated the following:

(1) The content of $3CaO.SiO_2$ by microscopic analysis is greater than by calculation, except for very low Al_2O_3/Fe_2O_3 ratios.

(2) The content of $2CaO.SiO_2$ is less by microscopic analysis, except for very low Al_2O_3/Fe_2O_3 ratios.

(3) Microscopically determined "dark interstitial" material is less than calculated $3CaO.Al_2O_3$ for low Al_2O_3/Fe_2O_3 ratios and greater for high Al_2O_3/Fe_2O_3 ratios.

(4) Microscopically determined "light interstitial" material is greater than calculated $4CaO.Al_2O_3.Fe_2O_3$ for low Al_2O_3/F_2O_3 ratios and approximately equal for high ratios.

Qualitative and quantitative microscopic analyses indicate that the crystalline compounds present are not pure, but contain limited amounts of material in solid solution. Glass is present in all the samples studied. A comparison of observed heats of solution with those calculated from chemical analysis and from microscopic analysis shows a fairly close correspondence, but it is pointed out that the assumptions on which the calculations by both methods are based are inexact.

Improvements in Clinker Grinding.

AT the works at Silica, Ohio, of the Medusa Portland Cement Co., three different arrangements for grinding clinker have been used in the past few years.

This is a wet-process plant operating three 10-ft. by 150-ft. kilns with a combined capacity of 135 barrels per hour. In *Rock Products* for October, 1937, a series of improvements were described, including rearranging the raw grinding department; installation of heat recuperators and two-stage clinker-cooling unit mills to fire the kilns; and closed-circuiting of the clinker grinding compartment mills with an air separator. These improvements reduced operating costs, increased the grinding capacity for raw materials and clinker, and produced a clinker easier to grind. The raw grinding department (wet process) comprises preliminary grinding through two type 85 kominuters in circuit with six Tyler Hum-mer screens with a total capacity of 200 barrels of slurry having a fineness of 97½ per cent. passing a 100-mesh sieve.

Prior to 1936 clinker was cooled to about 550 deg. F. through single-stage rotary coolers and was ground in three 7-ft. by 22-ft. Compeb mills. The first 7-ft. of the length of the mills were the preliminary sections with 14-ft. of the length effective as tube mills. The capacity of each mill was 50 barrels of cement but the surface area was only 1,425 sq. cm. per gram. The mills each had centre feed and peripheral discharge. Air separation was introduced in 1936, and clinker cooling was reduced from 550 deg. F. to about 150 deg. F. by the addition of heat recuperators on the kilns, followed by a rotary cooler. The clinker from the secondary cooler was conveyed to three 1,000-barrel mill feed bins. The results of the improvements are described in the same journal for June, 1939.

An 18-ft. mechanical air separator was installed in closed-circuit with two of the 7-ft. by 22-ft. compartment mills, and the third mill could be operated either in open circuit or in conjunction with the air separator. The compartment grid-bars were opened to approach tube-mill conditions when air separation was added. The clinker feed into each mill was regulated by a variable-speed motor-driven belt feeder with a constant slot opening and synchronised with the gypsum feed. With this installation it was hoped that two mills would be sufficient, but the third mill was necessary. The mills were fed by rocker-type feeders and the separator rejects returned into the mills with the fresh feed. The capacity of each mill with this arrangement was 60 barrels, an increase over that for open circuit, and the surface area was increased to 1,550 sq. cm. per gram. The circulating load was maintained at about 75 per cent. of the feed, the feed into the separator from each mill being 105 barrels per hour, with a reject stream of 45 barrels per hour added to the fresh feed of 60 barrels per hour.

After operating this circuit for a short time, the finish grinding department was rearranged to increase further the specific surface. One of the compartment mills was converted into a preliminary ball mill with double-end feed and common centre discharge, leaving the other two compartment mills now converted to straight tube mills for finish grinding. The preliminary mill is closed-circuited with screens and the two tube mills with the 18-ft. air separator.

The clinker, which is hard-burned and cooled to 150 deg. F., is fed into one end of the mill (axial feed) from the 1,000-barrels capacity bin overhead. Clinker is introduced into the ball mill over a chain-belt pan-feeder with gypsum proportioned into the pan feeder off the same drive. The feeder arrangement is driven by a constant-speed motor.

Feed into the ball mill is regulated by a Hardinge " electric ear," a recent development designed to prevent overloading or underloading of grinding mills. The unit consists of a sound-box which is tuned to a definite sound in the mill while revolving, and is set to maintain this sound which is a measure of the mill loading. The sound-box is set close to the mill and is in circuit with an electric switch-box for starting and stopping the mill feeder-motor. The bed of clinker resting on the open feeder is first regulated and the sound-box adjusted to shut off the feed when a dull sound indicates that the mill has too great a load

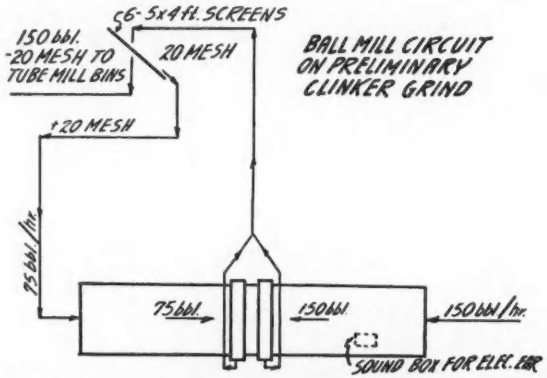


Fig. 1.—Flow diagram on preliminary clinker grind. Note " electric ear " installation to regulate feed.

for the best grinding efficiency. The instrument has proved far more sensitive than the human ear, and has helped to maintain a constant and definite circulating load between the screens in circuit with the mill. The " ear " can be tuned to give a definite mill output or fineness of grind.

The half of the mill in which maximum grinding takes place (controlled by the " ear ") is charged with 500 5-in., 500 4-in., 1,000 3½-in., 2,000 3-in. and 2,000 2½-in. forged steel balls weighing a total of 16·4 tons. This end of the mill discharges peripherally through ¼-in. openings in the grid bars into a sump and is fed in equal proportions to six 5-ft. by 4-ft. single-deck screens by a chain-bucket elevator at 60-ft. centres and 16-in. screw conveyors. The screens make a separation at 20-mesh. The rejects are spouted axially into the opposite end of the ball mill and discharge at its centre into the same sump into which the other end of the mill discharges. The grid bars on the tailing end of the mill are spaced at $\frac{3}{32}$-in. and the grinding media are forged steel balls graded from 2½-in. to 1-in. diameter.

As shown in *Fig.* 1, the ball mill is producing 150 barrels per hour of material passing a 20-mesh sieve with a circulating load of 50 per cent. This material is then passed through the other two 7-ft. by 22-ft. mills. By increasing the tube-mill grinding length from 14 ft. to 22 ft., there is more length effective in producing the necessary "flour" to get cement with a high surface area. Material passing the 20-mesh sieve is passed into the two 1,000-barrel feed bins over the mills. These bins originally contained clinker, but in the present lay-out are a reserve should a ball mill break down. The tube mills, each of which is charged with 50 tons of $\frac{7}{8}$-in. grinding media, receive their feed axially and discharge peripherally.

The tube mills are closed-circuited with the 18-ft. air separator (*Fig.* 2) having a circulating load designed to give several passages of the material through the mills. Material passing the 20-mesh sieve is fed from the large bins through an inclined screw dog-leg feeder followed by a trunnion screw feeder driven through variable-speed motors. Each bin is provided with compressed-air

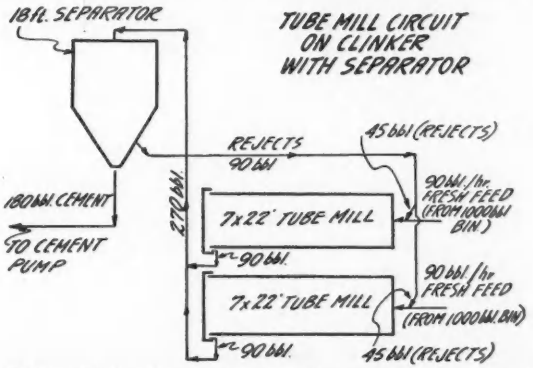


Fig. 2.—Tube mill in closed circuit with separator in finish grinding.

lines near the bottom to aerate the material. The capacity of each mill is 90 barrels per hour with a surface area of 1,600 to 1,800 sq. cm. per gram. The circulating load is 50 per cent., as shown in the diagram. The output is the equivalent of that produced before with three mills and the air separator, but the surface is better. Grinding costs have been reduced and maintenance expense is lower. The power load can be more easily balanced. Generally the ball mill is kept operating all the time. One tube mill operates continuously and the other half-time, which is usually sufficient. Each of the three mills revolves at 20 r.p.m.

In the mill room a bag-type dust collector with 2,700 sq. ft. of cloth surface has been installed with ducts leading to the mill discharges and at the top of the bucket-elevator to the separator. The collector relieves the air pressure built up in the elevator and recovers fine cement particles, which are returned into the tailings. Finished cement is pumped into the silos by a 6-in. Fuller-Kinyon pump.

Slurry Agitation.

IN the July, 1939, number of *Pit and Quarry*, Messrs. A. W. Catlin and R. R. Mills, of the Manitowoc Engineering Works, deal with the arrangement of slurry agitation plant in wet-process cement plants. The authors point out that in planning the slurry-blending, storage, and kiln-feed tanks consideration should be given to possible variations in the analysis of the raw material. The variation in lime content in the various blending tanks may be as much as 15 per cent. Under more favourable conditions the lime content of the raw material may be fairly uniform, and good control can be obtained by proper proportioning of the feed to the raw-grinding mills. For example, where the raw materials are limestone and clay, clay is pugged in a wash-mill using approximately 60 per cent. water and is fed by a pipe-line to the grinding mill. The limestone feed rate is determined by the capacity of the grinding mill at the desired fineness, and the feed of the clay slurry is varied by different size nipples to obtain proper proportioning of the mix. These considerations determine the arrangement of the slurry tanks.

Mechanical agitators have been used, but their first cost and the cost of operation is high compared with those of more modern equipment. Pneumatic agitators using compressed air alone have been used ; the Pachuca tank, operating on the air-lift principle, or the Parral tank, having a flat bottom with a number of air-lift columns, or a tank fitted with stationary vertical air pipes, all operate with compressed air only. Vertical air pipes require a large amount of air. In addition frequent cleaning of the tank is required to maintain the entire volume of the tank available for storage, since the unagitated portions of the tank build up gradually with a material which is very difficult to remove.

Slurry agitators serve two purposes, namely, agitating and blending. The term " agitating " is used to describe the action of maintaining, in a storage tank for example, uniformity throughout the entire volume of the tank as regards size of particles and chemical composition. " Blending " covers the case where slurries varying in chemical composition enter a blending tank and must result in a mix desired uniformly throughout the tank. The term " blending " is used to distinguish between agitating only and combined mixing and agitating. Present grinding practice requires that the raw materials be finely and uniformly ground and that the resultant slurry lends itself readily to agitation.

Most recent installations of agitators have used combined mechanical and air agitation. They consist in the main of a rotating arm with air pipes distributed radially so as to discharge over the entire area of the bottom of the tank. The rotating arm keeps the tank clear for its entire volume and also directs the air used for agitation. The compressed air gives the slurry what may be called a " boiling " action. The air bubbles released at the bottom and escaping to the top lighten the slurry column and cause it to rise. Also, the air bubbles cause the slurry to rise by what may be termed mechanical action, just as a paddle would act. In other words, the agitation accomplished by the air is to a large

extent the same as that accomplished by mechanical agitation but in a more efficient manner.

For blending slurries, with the proper design of equipment slurries varying as much as 15 per cent. in lime content can be uniformly mixed throughout the volume of a tank 38 ft. in diameter and 25 ft. deep in 2 hours using, under these conditions, compressed air continuously. Maintaining agitation in a storage tank, with present grinding practice, requires the use of compressed air at about half-hour intervals. In both agitating and blending the result should be that the lime content of the entire volume of the tank should be uniform within 0.1 per cent. This for all practical purposes gives a perfectly uniform slurry, as the method by which routine chemical analyses for lime are made may be in error by this amount.

The aim in the designing of agitating equipment should be to use air as economically as possible with freedom from operating difficulties. These operating difficulties consist of keeping the air pipes from plugging and avoiding trouble with any bearing which may be buried in the slurry.

In order to prevent the pipes from plugging an efficient method is to use a straight pipe without any restrictions at the outlet end, while, at the same time, air from the main air line or compressor should be directed through only one outlet at a time to the bottom of the tank. When air is directed to one pipe only any tendency of this pipe to plug immediately allows the air pressure to build up to the compressor pressure. In addition, when the air is turned off from this pipe, an air column remains in the pipe, preventing the slurry from entering. This principle assures elimination of the difficulty of plugged pipes and is very readily accomplished.

The step bearing has in the past given some trouble but by using a design based on the principle of the diver's bell, in which entrapped air in the bearing prevents the slurry from entering the journal, the problem of maintaining the step bearing commonly used in this type of agitator has been overcome.

The cost of slurry agitation depends upon the requirements of blending and storage capacity. A plant having an annual capacity of 1,250,000 barrels can be operated at a power cost for driving the agitators and compressing the air of 2 mils per barrel, when the proper mix can be closely approximated at the grinding mills and the total slurry storage is sufficient for three to four days' output.

In order to keep down costs, it is desirable to use the minimum amount of air. If the agitator used requires air, for example, at half-hour intervals, and feeds air to one pipe at a time, the average air requirement for each agitator can be estimated at 25 cu. ft. of free air per minute. During the time the air is blowing from one pipe, 175 cu. ft. of free air per minute will be released. Since a number of agitators can be synchronised to blow alternately, advantage should be taken of this fact in order to maintain a low compressor load. If, for example, air blows in one agitator for 5 minutes and is shut off for 30 minutes, as many as seven tanks can be used and still maintain the maximum compressor load of 175 cu. ft. of free air per minute. This can be accomplished while obtaining perfect agitation.

In dealing with cement slurries it is desirable to establish certain of their physical characteristics in addition to their chemical analyses. It is a simple matter to ascertain the weight per cubic foot and the moisture content. Given these data as a basis, other values may be determined by means of formulæ in which the following nomenclature is used :

S = Percentage of solids by weight, expressed as a decimal.
S_1 = Percentage of solids by volume, expressed as a decimal.
L = Percentage of liquid by weight, expressed as a decimal.
L_1 = Percentage of liquid by volume, expressed as a decimal.
G = Specific gravity of solids.
G_1 = Specific gravity of slurry.
V = Cu. ft. of slurry per ton.
V_1 = Cu. ft. of slurry per ton of solids.
W = Weight of slurry in lb. per cu. ft.

When the specific gravity of the liquid is unity, as water, then

$$(1)\quad S = 1 - L$$

$$(2)\quad S_1 = \frac{S}{S + GL}$$

$$(3)\quad L_1 = \frac{L}{\frac{S}{G} + L} = 1 - S_1$$

$$(4)\quad G = \frac{SW}{62.5 - WL}$$

$$(5)\quad G_1 = \frac{W}{62.5}$$

$$(6)\quad V = \frac{32}{G_1} = \frac{2000}{W}$$

$$(7)\quad V_1 = \frac{32}{GS_1} = \frac{V}{S}$$

These formulæ have been amplified to a greater extent than is generally necessary for dealing with cement slurries in order that they may be applied to slime pulps, such as cyanide slimes, in metallurgical practice where tonnages and volumes are important. The weight of a cubic foot of water is taken at 62.5 lb. under all conditions to simplify the equations, this figure being considered sufficiently accurate for all practical purposes.

Where compressed air is employed, either in whole or in part, to provide agitation, it is desirable to know the pressure required to force the air through the slurry load in a given agitation tank. The theoretical pressure may be calculated from the fundamental formula in hydrostatics,

$$p = 0.433h$$

by introducing the factor G_1 (specific gravity of the slurry). Therefore the formula becomes

$$p = 0.433\ G_1h,$$

in which p = air pressure in lb. per sq. in. and h = the static head or depth of

slurry above the air-admission point. This theoretical pressure should be increased, as conditions may necessitate, to provide for pressure drop through friction in air-lines, valves and fittings.

As an example of the application of these formulæ, the following results have been calculated from actual conditions where a slurry contained 32 per cent. of moisture by weight (L) and weighed 106 lb. per cu. ft. (W). The calculations, which are simple, are omitted.

Percentage of solids by weight	(S)	68.0
Percentage of solids by volume	(S_1)	45.75
Percentage of liquid by volume	(L_1)	54.25
Specific gravity of solids	(G)	2.52
Specific gravity of slurry	(G_1)	1.70
Cu. ft. of slurry per ton	(V)	18.87
Cu. ft. of slurry per ton of solids	(V_1)	27.75

Notes on Slurry Filters.

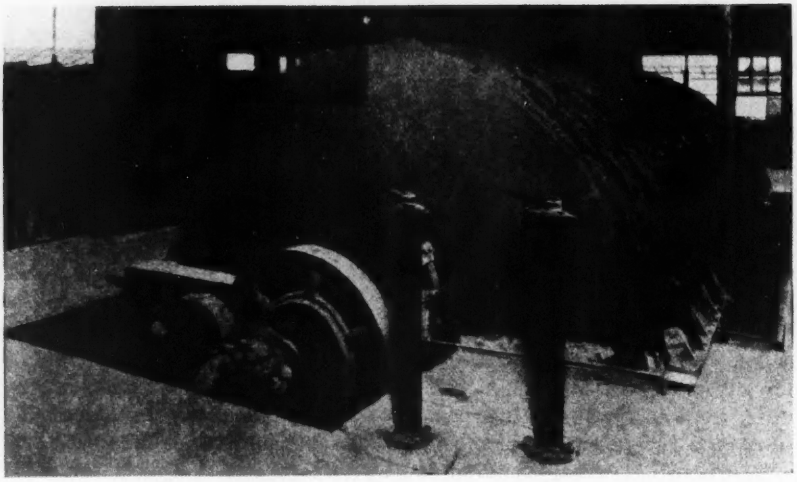
IN a recent number of the Cement Mill Edition of "Concrete" it is stated that by the end of 1934 57 kilns were equipped with slurry filters. The writer continues:

Filters used in dewatering cement slurry are of two general types—the drum type and the disk type. In each case the wet slurry is brought into contact with a fabric to which suction is applied and a portion of the water is drawn off. A cement slurry may contain from 35 to 50 per cent. of water by weight, and the desired moisture content may be around 18 to 19 per cent. It is estimated that the reduction of moisture from 35 per cent. to 19 per cent. involves the removal of 150 lb. of water per barrel of clinker produced. The evaporation of 150 lb. of water requires approximately 100,000 B.T.U. of heat, representing 8 lb. of coal having a heat value of 12,500 B.T.U. per lb.

The saving of fuel is one of the major advantages obtained by dewatering the slurry before it enters the kiln. More complete burning of the clinker is another result. Because the filter cake is completely dried more quickly than the original slurry, the subsequent calcining and clinkering temperatures are reached at earlier stages in the travel of the material through the kiln. Then, as a result of the more complete burning of the clinker, grinding is accomplished with less expenditure of power. Because of the low moisture content of the filter cake compared with the original slurry, it may be fed to the kiln more rapidly, with a resulting increase in output. Another advantage is that dewatering of the slurry eliminates balling of the raw material and the formation of mud rings within the kiln.

In a cement plant where a drum-type of slurry filter was installed the moisture content was reduced from 33 per cent. to 19 per cent., fuel consumption was reduced by 15 per cent., the output of the kilns was increased by 10 per cent., and the clinker produced a cement of higher strength. In another plant in which slurry filters were installed in 1930 fuel requirements were reduced by 12·2 per cent. and the output of the kilns was increased 16·6 per cent. In less than two years the saving in fuel alone compensated for the cost of the installation. It is estimated that 1½ cents per barrel of clinker produced will, in most cases, cover the total cost of operation.

The disk type, shown in the illustration, has the filtering fabric attached to disks built up of wedge-shape sectors carried on a shaft which contains a number of separate compartments. The disks, while under vacuum, are revolved through the slurry, in tanks, and a layer of slurry is picked up on each side of the disk. After a sector of the disk emerges from the slurry tank, the slurry adhering to the disk loses its moisture rapidly. The suction draws the excess water through the fabric, and it passes out through the shaft. The sector of the disk remains under vacuum, through other mechanical connections, until it reaches the position of discharge. As the rotation carries the sector beyond the position of discharge, low-pressure air is applied by a pressure pump. This action inflates the disk, or bag, with air, and as this inflated part of the circular disk moves down between



the scraping edges of the filter-cake discharger, the cake is scraped off, dropped to a belt conveyor, and transported to the kiln-feed mechanism.

Some raw materials are of such a nature that moisture cannot be extracted economically from the slurry. For example, clays in a very finely divided or colloidal state cannot be dewatered successfully.

The Care of Electric Plant.

[CONTRIBUTED].

In positions where the atmosphere is not likely to be corrosive, ordinary industrial-type electric motors suitably protected from the possibility of mechanical damage are satisfactory. Where the atmosphere is corrosive and contains fumes or dust further precautions are necessary. Corrosive fumes attack the insulation on the coils, causing it to deteriorate, and bare metal surfaces will be subject to corrosion. Where the atmosphere is damp and warm, severe corrosive action will soon start. In these situations the most suitable motors are undoubtedly totally-enclosed ventilated motors, the ventilating air being drawn from the outside of the building and circulated by a fan. Unventilated enclosed motors are not suitable where there are corrosive fumes, as vapour finds its way into the motors and, not being removed by the ventilating air, sets up corrosive action. Open-type motors where the air has free access to all parts may be satisfactory under slightly corrosive conditions, but where the atmosphere is definitely corrosive they are unsatisfactory.

Any dust which collects on the armature and field coils is liable to be corrosive, and this in time may lead to the formation of acids which will attack the insulation. Cleaning with a dry cloth twice weekly will keep the coils free of dust or deposit. A good coat of shellac or acid-resisting varnish on the coils will help to protect them from corrosion. Further possible trouble may develop due to air drawn through the commutator risers into the armature, deposits being formed inside the commutator which will attack the insulation. The best way to prevent this is to fill the spaces between the risers by intertwining muslin between the bars. This will, however, impede the ventilation and cause the armature temperature rise to be greater, and if this temperature rise is excessive the load on the motor will have to be reduced. Cowls may be fitted to prevent air being drawn into the armature.

Flexible brush "pigtails" are also liable to attack. It is best to tin the copper, as tin is more resistant to corrosion. Connections should first be tightened and then given a coat of shellac. Commutators are liable to blacken quickly and the only remedy is frequent cleaning with sandpaper. Where commutators are recessed the slots should be frequently cleaned out to remove any dust, etc.; an old toothbrush is satisfactory for this purpose.

Starting rheostat and controlling switches need frequent cleaning and inspection, otherwise they will not keep in order for long. In the case of large motors a completely-enclosed starting panel is generally used, giving absolute protection from dust, but this safeguard is not usually provided for smaller starters, the rheostat, switch, and fuses being mounted on angle irons and unprotected from the atmosphere. It follows that smaller starters require more frequent cleaning than enclosed ones. A complete starting unit consists of a

double-pole switch, fuses, and a starting rheostat. Circuit breakers may be used with large motors in place of fuses. It is advisable to inspect the switchgear every three months and clean it every month, or oftener if necessary.

The component demanding most attention is the starting rheostat. To clean this the cover should be removed, exposing the contacts and starting arm. During the course of the starter's operation the contacts become pitted, burned, and oxidised, especially the first few contacts. The best way to clean them is to place a piece of fine glass-paper under the starter arm, with the rough side towards the contacts. The starter arm should then be moved backwards and forwards until the contacts are clean and bright. Any dust caused during this operation must be removed with cloth and bellows.

The overload release should also be examined to see if it is working properly, and the no-volt coil inspected to see whether the insulation has deteriorated. The working temperature of these coils is high, and this imposes a severe strain on the insulation. The insulation is bound to burn out in course of time, but the average working life of a no-volt coil should be at least five years.

In alternating current starters burn-outs may be more frequent. In these starter plungers no-volt coils are largely used, and owing to the deposit of dirt they are likely to stick. When this happens the current flowing in the coil is many times the normal amount, increasing the heating and, if continued long enough, causing a burn-out. The plungers should be removed from time to time and cleaned. When replacing them, a trace of thin oil should be applied to all moving parts.

In even the cleanest surroundings a certain amount of dust will find its way on to the " business " ends of the switchgear. In addition the bright parts of the switches are likely to be affected by moisture or fumes. Cleanliness is thus of considerable importance, and though with modern designs many examples can be quoted of switchgear and appliances giving good service under most unfavourable conditions, these should rather be looked upon as proof of good design and sound workmanship than as precepts to follow in the use of switchgear.

Surface cleaning is not the only task that is called for if switchgear is to be maintained in really good condition. Marble and enamelled slate for switchboards is not so prevalent as it was, but there is still plenty of it in factories to-day. It should never be cleaned with an oily rag, but should be kept clean by daily dusting with a soft brush and an occasional clean or rub with a damp soapy cloth. Enamelled slate may be repolished with a rag and a smear of boot polish. Oiled slate panels should be cleaned with a clean rag moistened with turpentine.

Metal polish should on no account be used for cleaning the bright parts of instruments ; a rub with a rag and a trace of vaseline is far better. The blades

of knife switches and metal parts generally can be rubbed with a slightly oily rag and, although oil is generally looked upon as an insulator, a very thin film of oil left on the switch blades and other parts does not materially increase contact resistance. The back of the board is as important as the front, and dust and dirt should not be allowed to accumulate there just because it is not so readily visible.

The insulation of electrical equipment is of prime importance. If the insulation becomes defective there will be electrical leakage to earth and possibly a burn-out. Although the insulation may be perfect when new, it deteriorates due to age and wear and tear, and this is hastened by any adverse conditions under which the machine works, such as overheating, exposure to gaseous fumes, or damp. Some insulations quickly absorb atmospheric moisture, which greatly reduces their insulating properties.

Inspection alone will not show the condition of the insulation as regards resistance to electrical leakage; this can only be ascertained by a test by a reliable testing set. The method of testing consists in subjecting the conductors to a small current at a high voltage (say 500). As the conductors are insulated the only current which can pass is the leakage current which passes through the insulation; therefore the amount of current which flows indicates the condition of the insulation. The Megger insulation testing set works on these principles. The instrument consists of a small generator (actuated by a handle on the outside of the case) and a scale and pointer on which the leakage is indicated. The scale is graduated in ohms and megohms and shows the exact resistance offered by the insulation. Where the insulation between two conductors has to be tested it is only necessary to connect them to the two terminals on the instrument, turn the generator handle until the speed recommended in the instructions is attained, and the value of the resistance will be shown by the deflection of the pointer on the scale. Where the resistance of a single conductor is to be tested it should be connected to one terminal on the instrument, and the other terminal connected to a good earth such as a water main. Then test as before. If the resistance value is steady the insulation is in good condition; unsteady readings demand further investigation. Fluctuating and jumpy readings are often caused by a surface deposit of metal dust, or possibly metallic fragments embedded in the insulation. The insulation resistance between adjacent conductors should be tested, and, in addition, the resistance between each conductor and earth.

An electric generator or motor can be tested as follows. The line terminal of the Megger set should be connected to the commutator or an exposed conductor on the machine, the earth terminal being connected to a bright part on the frame or core. The handle on the instrument case should then be turned at the proper speed and the reading on the scale noted. If the value of the resistance is satisfactory there is no need for further testing. If the resistance is below the minimum set, then the various circuits should be isolated and tested

separately until the faulty insulation is found. It is advisable to test the insulation while the windings are warm, as the resistance will be lower than when cold. A good minimum insulation resistance to adopt for generators and motors is one megohm, although in practice this figure is usually greatly exceeded.

Motor starters should be tested between the circuits of the starter and the earthed frame, first with all circuits of the starter completed, and then between the main terminals with all the circuits broken. The value of the resistance should not be less than one megohm.

In many cases the cause of electrical machinery showing a poor insulation resistance is through its being in a dirty condition. Thorough cleaning and blowing out should give a considerable improvement. Another possible cause is that the windings are damp. Most insulating materials rapidly absorb moisture from the atmosphere, which lowers their resistance and increases the risk of leakage. In these cases the machine should be dried out; the best way to do this is to run the motor on a reduced voltage until the windings are warmed and continue until the insulation resistance is normal.

Bowl Classifiers in Conjunction with Slurry Thickeners.

OUR United States contemporary, *Concrete*, states that the use of slurry thickeners in combination with bowl classifiers in the raw-grinding operations of wet-process cement plants seems to find greater favour on the American continent than elsewhere. In England, for example, the tendency in wet-process operation is to utilise longer kilns as a means of getting rid of the moisture in the slurry, thereby avoiding the installation of features such as slurry thickeners and slurry filters.

The operation of a typical installation is shown in *Figs.* 1 and 2, which show the principal mechanical features.

The bowl classifier shown in *Fig.* 1 is in closed circuit with the secondary compartment of a compeb mill. It is equipped with rotating as well as reciprocating rakes. The diameter of the bowl in which the rakes operate is 25 ft., and the total length of the classifier is 48 ft.

A dilute mass overflowing from the preceding primary classifier joins the pulpy mass discharging from the secondary compartment of the compeb mill, and the entire mass is further diluted to a thin slurry upon entering the bowl classifier.

The problem is to maintain the velocity and the turbulence of the diluted slurry at points such that only the minus 200-mesh particles will remain in suspension. This is accomplished through control of the velocity and minimising the turbulence. The flow from the primary classifier and the secondary compartment of the mill enters the bowl classifier at the centre (*Fig.* 1) and is

directed downward. The larger particles in the slurry settle to the bottom, while the finer particles move with the water in a circular or spiral motion toward the periphery of the bowl, the current slowly reducing in velocity as the diameter of the movement is increased. In consequence more and more of the particles settle to the bottom, since the gradually reducing velocity permits smaller and smaller particles to settle. This action continues until the periphery of the bowl classifier is reached, where the only raw-material particles remaining in suspension are fines that would pass the 200-mesh sieve. This very highly-diluted slurry at the rim of the bowl classifier, carrying only the fines (minus 200-mesh), constitutes the classifier overflow.

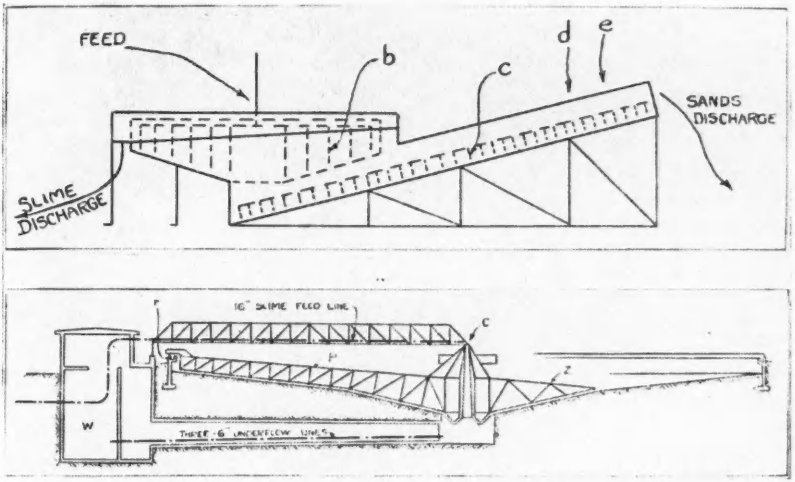


Fig. 1 (Above): Bowl classifier in closed circuit with the secondary compartment of the raw-grinding mill, and operating in conjunction with a slurry thickener. Fig. 2 (Below): Slurry thickener.

The very slowly rotating rakes (*b* in *Fig.* 1) move with sufficient speed to dispose of the settled particles, raking them down the conical bottom of the bowl into the area of the reciprocating rakes (at *c* in *Fig.* 1), to be conveyed up the incline and returned to the feed-well of the secondary grinding compartment of the mill by means of a screw conveyor and open-gravity launder. The clay slip from the wash mill is also introduced into the circuit at this point.

The bulk of the material returned to the secondary grinding compartment from the bowl classifier is circulating load, inasmuch as the discharge from the secondary compartment is considerably greater than the overflow from the primary classifier. The movement of rake *b* must, however, be so slow that it will not over-agitate the water, or dilute slurry, in the bowl.

The overflow from the bowl classifier is conducted by gravity through a

16-in. pipe to the slurry thickener (*Fig.* 2), where it is dewatered to a density approaching that of ordinary slurry. This thickener is 225 ft. in diameter, 7 ft. deep at the periphery, and 22 ft. deep at the centre. The rakes consist of a long drive-truss spanning the radius of the thickener (shown at *p* in *Fig.* 2), and three shorter members 90 deg. apart, one of which is shown at *z* in *Fig.* 2. Curved blades attached to each of the four trussed rakes gradually scrape the slowly dewatering mass to the three points of discharge in the centre discharge cone. These rakes, having a velocity of only 1½ revolutions an hour, accomplish this operation with a minimum of agitation of the mass.

A trussed steel bridge from the edge of the thickener to the centre (shown in *Fig.* 2) supports a walkway, a 4-in. water service line, a 2-in. compressed-air line, a slurry recirculating line, power lines for feeding the collector rings that pick up the current for propelling the rakes, and the 16-in. welded pipeline previously mentioned as the means for delivering the diluted slurry overflow from the bowl classifier to the centre of the thickener. The purpose of the recirculating line is that of returning the dewatered slurry from the sump (at *w* in *Fig.* 2) back into the thickener at times when the slurry cannot be disposed of otherwise.

In connection with what has just been said about the possible need for returning some of the dewatered slurry from sump *w* to the thickener, it must be remembered that the system must be kept in motion. Inasmuch as the raw-material particles are constantly settling out, they must not be permitted to form a slurry too thick to pump. For this reason, also, the rakes in the thickener must not be permitted to stop operating for any long period. To provide for this contingency, the manufacturers of this equipment have developed an underspeed alarm as part of the installation.

The diluted slurry from the bowl classifier enters the slurry thickener at the centre (through the 16-in. welded pipe) and discharges into a feed-box, by means of which the stream is broken up and its velocity is greatly reduced before it enters the mass in the thickener. The entire mass in the thickener moves in a manner similar to that in the bowl classifier, with a spiral motion working out toward the edge of the basin constituting the thickener. The velocity is constantly decreasing, so that smaller and smaller particles are permitted to settle out and slowly raked to the centre discharge cone.

By the time the current reaches the rim of the thickener, the overflow from the thickener, which discharges into the launder at *r* (*Fig.* 2), carries an appreciably smaller quantity of solids per unit of volume than the water of the adjoining river into which this overflow is discharged.

CEMENT AND LIME MANUFACTURE

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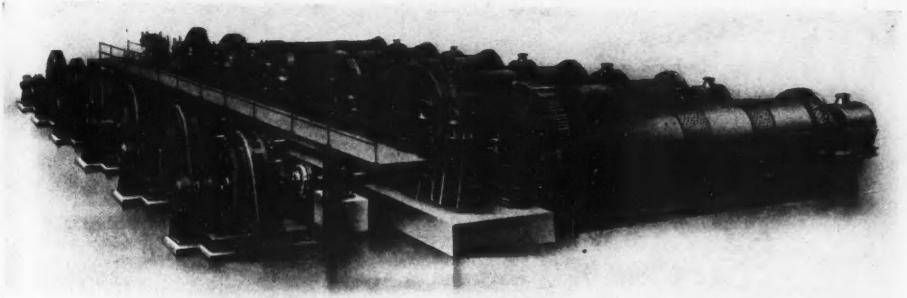

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